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The Mechanical Composition of Wind Deposits

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CONTENTS.

GENERAL STATEMENT.

The great lightness of the air, when compared with water, and the comparatively high velocity of its currents will necessarily render any materials it may carry and deposit somewhat different in composition and structure from those which are laid down in water. They are as a rule finer, they exhibit a different bedding and are more capriciously placed. These characteristics are familiar in a general way. It is here desired to present more exact information on this subject, particularly as to the mechanical composition of these deposits; and to show how this changes under varying circumstances of deposition. It is hoped that this may lead to a more certain identification of wind sediments, wherever they may be found. The inquiry seems to be of special importance in connection with the study of superficial deposits.

Samples of different kinds of materials moved by the wind have been collected from different places of desposition and from the atmosphere directly for this study. Each of these has been separated into grades of different coarseness and the per cent of the weight for each grade *)

*) The particles ranging between two successive separations will here be referred to as a *grade*. In the analyses these separations were made in a uniformly decreasing series of diametrical dimensions, the diameter of the largest particles in one grade having twice the length of the diameter of the coarsest particles in the next finer grade. The coarsest grade consists of rock fragments with diameters ranging from 16 to 8 millimeters, the next from 8 to 4 mm., and so on, down to particles measuring from $\frac{1}{128}$ to $\frac{1}{256}$ mm. Below this size no separations have

in each sample has been determined. It appears that all of these samples and presumably the greater part of such materials as owe their present position and arrangement to the action of the atmosphere may be referred to some one of four categories. These may be characterized as 1) lag gravels, or coarse residual deposits in the rear of

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been made, particles so minute constituting only a very small proportion of even the finest atmospheric sediments. In general, when the finest grades have been found in a quantity amounting to only a small fraction of a per cent of any sample, they have been neglected. For the sake of convenience the following designations of the different grades will be used in this paper:

Coarse gravel..........	diameter	from 8	to 4	millimeters.
Gravel......................	"	" 4	" 2	"
Fine gravel..............	"	" 2	" 1	"
Coarse sand.............	"	" 1	" $\frac{1}{2}$	"
Medium sand...........	"	" $\frac{1}{2}$	" $\frac{1}{4}$	"
Fine sand.................	"	" $\frac{1}{4}$	" $\frac{1}{8}$	"
Very fine sand.........	"	" $\frac{1}{8}$	" $\frac{1}{16}$	"
Coarse dust..............	"	" $\frac{1}{16}$	" $\frac{1}{32}$	"
Medium dust............	"	" $\frac{1}{32}$	" $\frac{1}{64}$	"
Fine dust..................	"	" $\frac{1}{64}$	" $\frac{1}{128}$	"
Very fine dust..........	"	" $\frac{1}{128}$	" $\frac{1}{256}$	"

Down to the particles measuring $\frac{1}{8}$ of a millimeter all the separations were made by sieves, and below this the per cent of the weight of each grade was determined by microscopic measurements and by calculation from the number of grains counted in each grade. In nearly all samples which have been examined, there is a medium grade, which is present in greatest quantity, while the other grades diminish in bulk the more the size of their particles differ from the medium grade. The latter will here be called the *chief ingredient*, or the *maximum*, and the two decreasing series on either side will be referred to as the *coarse* and the *fine* admixtures.

In this connection I desire to state that I am under great obligations to Professor Milton Whitney, of the United States Department of Agriculture, from whom I received much valuable information regarding the mechanical analysis of superficial deposits, in examining a series of Illinois soils some years ago. Down to medium sand, the grades here adopted correspond to the coarser grades in the scale which he has adopted for soil analysis. Below this size I have found it necessary to make use of another scale. In the analysis of soils it is of particular importance to determine the quantity of "clay" consisting of particles below the size of $\frac{1}{200}$ mm., while in an investigation of the nature of the sorting effected by different mechanical forces, all the grades present in any considerable quantity are of equal significance. In the separations here made the sizes of the fragments in the successive grades increase uniformly in a geometric ratio.

sand dunes; 2) drifting sand, constituting the familiar dunes in dry and sandy regions; 3) fine sand, which is soon dropped by the wind in the lee of drifting dunes; 4) and dust, which only slowly settles out of the air far away from the place where it was raised.

Numerous observations on known eolian deposits in the field and on the mode of action of the wind have also been made to supplement this special study of the mechanical composition of wind sediments, and these will be drawn upon in the discussion of the other data.

LAG GRAVELS.

In many places where atmospheric erosion is going on, streaks of gravel are to be seen, partly covering the ground. Most often this gravel forms a thin veneer which partly protects the ground from further erosion. Though the present position of this material is due to the action of the wind, it is quite evident that it has not been transported very far. The deposits from which it has been derived may lie close by, and they are never far off. Commonly it is a bank of sand, part of which has been removed. The finer grades have been blown away, exposing these larger fragments to the force of the wind, which apparently moves them by undermining and rolling. They sometimes occupy the hollows on the eroded ground. It is evident that the coarseness of this gravel renders it much less subject to the action of the winds than the finer materials. Occasionally it may be found partly or wholly covered by finer materials, but on the

whole it is continually left in the rear of these, which follow the winds with greater promptness. Only ten samples have been examined. These were collected at eight different localities in the central part of the United States, as given in the table of analyses (Tab. I). It is not likely that these few samples adequately represent the composition of similarly formed deposits in other localities. The largest rock fragment in the lot measured only a little over eight millimeters in its longest diameter. It was part of a sample consisting of flat chips of a hard shale. Pebbles over four millimeters in diameter were present in four of the samples. All the other, with one exception, had pebbles over two millimeters in diameter. The different grades are rather indiscriminately mingled, in a manner determined by the caprices of the wind. Five of the samples have two maxima each. The chief ingredients vary from fine gravel through coarse and medium sand to fine sand. In three of the samples ninety per cent of the weight is distributed among five different grades; in six, among four grades; and in one, among three. In an average of all ten samples ninety per cent of the weight is distributed among five grades. The highest maximum in any grade is sixty-eight per cent and the lowest is twenty-five. The average height of the highest maxima is forty per cent.

The lag gravels are the most heterogenous of all the wind deposits. They are generally distinctly stratified. The fine admixtures are sometimes present as an original constituent of the eroded ground, but they may sometimes also be deposited with the gravels by the lighter winds. Compared with water-bedded materials of the

same coarseness, the layers are more irregular and thinner. Pebbly layers as much as an inch in thickness are extremely uncommon. On the whole gravels of this kind form very insignificant deposits, where they have been seen. This circumstance does not render it unlikely that lag gravels may have a greater development in regions long exposed to the actions of the stronger winds.

DRIFTING SAND.

Lag gravels graduate imperceptibly into coarse drifting sand, which in the field always lies in front of the gravels, following the direction of the prevailing winds. Farther in this direction the coarse sand becomes in turn finer and finer, until the main deposit is reached, where it always consists of grains of a more uniform size. In fact the main bulk of all sand drifts, large enough to be called dunes, have been found to contain only subordinate proportions of sand grains measuring more than one fourth or less than one eigth of a millimeter in diameter.

Sand coarser than this is present as a maximum ingredient only in superficial layers of no very great thickness, which lie on the rear slopes of dunes. It forms an intermediate series between typical dune sand and lag gravels, and it is capable of being rolled rather than lifted by the winds. This is indicated by the circumstance that it is often the main ingredient on the crests of wind ripples, being heavy enough to remain resting in this exposed position, while the finer dune sand is lifted to the upward slope of the next ripple. It differs from the lag

Table I. **Mechanical Composition**

Length of diameter in mm.	1 Chips of shale from Edgemont, S. Dak.	2 From a "blow-out," Hooppole, Ills.	3 From a "blow-out," Hooppole, Ills.	4 From north of Mineral, Ills.	5 From rear of dune, Michigan City, Ind.
16—8	5.7	....	....	....	....
8—4	14.4	.6	.3	.8	....
4—2	33.1	14.5	10.1	27.4	29.5
2—1	35.1	18.6	35.0	34.5	43.4
1—$\frac{1}{2}$	10.3	16.6	23.9	4.2	7.2
$\frac{1}{2}$—$\frac{1}{4}$	1.0	25.7	20.4	10.8	4.3
$\frac{1}{4}$—$\frac{1}{8}$	.4	20.5	8.8	16.2	14.7
$\frac{1}{8}$—$\frac{1}{16}$	....	3.3	.4	5.3	.1
$\frac{1}{16}$—$\frac{1}{32}$	....	....	....	.2	....
$\frac{1}{32}$—$\frac{1}{64}$	....	....	....	....	....
$\frac{1}{64}$—$\frac{1}{128}$	....	....	....	....	....
$\frac{1}{128}$—$\frac{1}{256}$	....	....	....	....	....

Table II. **Mechanical Composition**

Length of diameter in mm.	11 Rear slope of a dune, Alliance, Neb.	12 Rear slope of a dune, Tampico, Ills.	13 Rear slope of a dune, New Boston, Ills.	14 Rear slope of a dune, Alliance, Neb.	15 Rear slope of a dune, Alliance, Neb.
16—8	....	....	....	....	....
8—4	....	....	....	....	....
4—2	....	....	.2	....	....
2—1	9.0	3.9	1.8	.2	.1
1—$\frac{1}{2}$	80.0	43.8	22.0	37.1	33.7
$\frac{1}{2}$—$\frac{1}{4}$	6.6	28.6	46.2	50.9	49.4
$\frac{1}{4}$—$\frac{1}{8}$	5.0	22.0	26.2	18.9	15.0
$\frac{1}{8}$—$\frac{1}{16}$	.1	1.7	2.8	1.7	.1
$\frac{1}{16}$—$\frac{1}{32}$	....	....	.2	....	....
$\frac{1}{32}$—$\frac{1}{64}$	....	....	....	....	....
$\frac{1}{64}$—$\frac{1}{128}$	....	....	....	....	....
$\frac{1}{128}$—$\frac{1}{256}$	....	....	....	....	....

of Lag Gravels.

6	7	8	9	10	
Bottom of a "blow-out," Alliance, Neb.	From rear of dune, Michigan City, Ind.	From wind-eroded ground, Ardmore, S. Dak	From rear of a dune, New Boston, Ills	From a "blow-out", Alliance, Neb.	Average.
....	....	....	....	....	.5
....	....	....	....	....	1.6
5.9	4.2	1.2	.1	....	12.6
1.4	28.0	4.1	26.1	11.5	23.8
23.5	19.9	15.0	62.6	68.5	25.1
30.7	15.2	33.5	19.3	8.5	16.9
34.6	31.5	24.9	1.4	8.5	16.1
4.2	.4	19.6	....	2.0	3.5
.3	....	1.9	....	....	.2
....	....	....	....	....	....
....	....	....	....	....	....
....	....	....	....	....	....

of Rolling Drift Sand.

16	17	18	19	20	
Rear slope of a dune, Hooppole, Ills.	Rear slope of a dune, Hooppole, Ills.	Rear slope of a dune, Hooppole, Ills.	Sand Drift, Griggs co., N. Dak.	Sand drift, Griggs co., N. Dak.	Average.
....	....	....	....	....	....
....	....	....	....	....	....
....	....	....	....	....	tr.
....	.2	....	....	.3	.5
12.4	9.7	6.2	19.3	14.0	27.8
34.6	44.4	39.2	45.2	42.9	33.5
33.0	40.7	29.4	30.7	37.9	25.3
17.2	4.0	23.4	2.4	2.5	5.5
2.0	.3	1.2	.4	1.8	.5
....	....	....	tr.	.3	tr.
....	....	....	....	....	....
....	....	....	....	....	....

gravels in being light enough to be rolled up a gentle slope, and to be moved without any undermining taking place. Eleven samples of such rolling drift sand, as it may be called, have been collected and examined (Tab. II). Its composition is much more uniform and regular than that of lag gravels. The proportions of the different grades arrange themselves in all the samples in two decreasing series on either side of a maximum, which in three cases consists of coarse sand and in eight cases of medium sand. In one sample the maximum grade constitutes eighty-five per cent of the whole sample. The smallest maximum is thirty-four per cent. All the maxima average fifty per cent in the eleven samples. Ninety per cent of each sample is distributed among only three grades in nine of the samples and among four grades in the other two. By different sampling, no doubt somewhat different results might be obtained. But these analyses indicate that there is a rapid increase in the power of the winds to roll quartz grains, when these begin to be less than one millimeter in diameter. The same is also indicated by the sudden decrease in several of the analyses of lag gravels in the percentages of the grades, when this limit of size is passed. (See analyses no. 1, 2, 3, 4, 5, and 7). The rock fragments which exceed one millimeter in diameter, are too large to be rolled up the rear slope of a dune and are left in the "blow-outs" as a characteristic ingredient in the lag gravels, but they are, as may be seen in the analyses, only very sparcely mingled in the sand which is rolled up the rear slope of a sand drift.

The sand which constitutes the main body of dunes has been found remarkably uniform in its mechanical

composition. Thirty-eight samples have been analyzed, coming from eleven different localities. These it will be well to briefly describe, together with the sand from each place.

On the north side of the Mississippi river at New Boston in Illinois an ancient terrace is blown up into a sand ridge about a mile in length. From all appearances the

Table III. **Mechanical Composition of Dune Sand from New Boston, Ills.**

Length of diameter in mm.	21 Rear slope of ripples in dune sand.	22 Dune sand.	23 Top of ripple in dune sand.	24 Front slope of dune.	Average.
16—8	....	....	....	....	....
8—4	.6	....	....	....	.1
4—2	2.8	....	....	....	.7
2—1	2.0	.1	....	....	.5
$1—\frac{1}{2}$	9.9	2.6	29.6	3.6	11.4
$\frac{1}{2}—\frac{1}{4}$	30.4	31.8	56.0	30.8	37.2
$\frac{1}{4}—\frac{1}{8}$	47.8	64.4	13.6	63.6	47.3
$\frac{1}{8}—\frac{1}{16}$	5.0	.6	.2	2.0	1.9
$\frac{1}{16}—\frac{1}{32}$	.4	....	....	1.0	.3
$\frac{1}{32}—\frac{1}{64}$	....	....	....	....	....
$\frac{1}{64}—\frac{1}{128}$	....	....	....	....	....
$\frac{1}{128}—\frac{1}{256}$	....	....	....	....	....

sand in these dunes has not yet travelled a half mile. The materials in the original terrace are quite heterogenous in composition (Tab. I). The coarse grades have not yet had time to be quite left behind but appear in a small quantity in some of the dune sand (no. 21). One of the samples (no. 23) was taken by skimming the surface on the crest of a ripple. This is unique among all the analyses of typical dune sand in having medium sand as its

Table IV. **Mechanical Composition of Dune Sand from the Shore of Lake Michigan, Michigan City, Ind.**

Length of diameter in mm.	25 Upper rear slope of dune	26 Dune sand.	27 Typical dune sand.	28 Near the crest of a dune.	29 From the crest of a dune.
16—8	....	....	....	....	....
8—4	.2	....	....	....	....
4—2	4.1	.1	....	....	....
2—1	7.4	1.1	....	12.4	....
$1-\frac{1}{2}$	14.1	8.2	.9	6.4	.4
$\frac{1}{2}-\frac{1}{4}$	26.7	25.1	20.7	13.8	6.0
$\frac{1}{4}-\frac{1}{8}$	45.3	64.0	76.8	65.2	92.6
$\frac{1}{8}-\frac{1}{16}$	.5	1.2	1.0	1.8	.6
$\frac{1}{16}-\frac{1}{32}$	....	.2	....	....	....
$\frac{1}{32}-\frac{1}{64}$	....	....	....	....	....
$\frac{1}{64}-\frac{1}{128}$	....	....	....	....	....
$\frac{1}{128}-\frac{1}{256}$	....	....	....	....	....

Table IV. **(Continued.)**

30 From the top of a dune.	Average.
....	....
....	tr.
....	.7
....	3.4
3.4	5.5
12.9	17.5
73.1	69.5
8.7	2.3
....	tr.
....	....
....	....
....	....

Table 5. **Mechanical Composition of Drifting Sand from the River Bluffs east of Cordova, Ill.**

Length of diameter in mm.	31
16—8	....
8—4	....
4—2	.4
2—1	10.5
$1-\frac{1}{2}$	14.0
$\frac{1}{2}-\frac{1}{4}$	25.9
$\frac{1}{4}-\frac{1}{8}$	52.2
$\frac{1}{8}-\frac{1}{16}$	6.0
$\frac{1}{16}-\frac{1}{32}$	....
$\frac{1}{32}-\frac{1}{64}$	....
$\frac{1}{64}-\frac{1}{128}$	....
$\frac{1}{128}-\frac{1}{256}$	....

maximum ingredient. Had it been taken a little deeper, it would have been more like the rest, for the coarser grains are least easily dislodged from this exposed position and remain, while the finer sand is blown away. Some coarse dust is still mixed in the sand at this place in one instance (no. 24). All taken together and compared with sand from other places, these samples may be said to be imperfectly sorted, owing no doubt to the recency of the inception of the wind action in this locality.

The dunes on the south-east shore of Lake Michigan have furnished the materials for six analyses (Tab. IV). These sand hills have been recently formed and are largely made up of sand that is freshly supplied by present wave action on the shore of the lake. In this place also the coarse grades occur with the typical dune sand in small quantities on the very top and front slope of the hills (see nos. 25, 26, and 28). But there is practically no coarse dust to be seen, presumably because no such fine material is present in the beach sand. This locality and the previous are the only ones that furnish instances of dune sand having a second maximum in the coarser grades (no. 21 and 28).

The bluffs facing the bottom lands of the Mississippi, east of Cordova in Illinois, are here and there being eroded by the northwest winds. Some sand taken from a small drift only a foot in height exhibits imperfect sorting like that observed in the sand from New Boston and Michigan City (Tab. V).

In Rice county in the central part of Kansas there is a tract of sand hills extending many miles along the little Arkansas river. These are derived from underlying late

tertiary beds. Their extensive development shows that the wind has been at work here for some considerable time. The sand is correspondingly uniform, and rock fragments of either extreme size are absent (Tab. VI). One of the analyses exhibits the mechanical composition of a single thin lamina in the dune (no. 34), evidently laid down under a uniform wind velocity. It is interesting as

Table VI. **Mechanical Composition of Dune Sand from Rice County, Kans.**

Length of Diameter in mm.	32	33	34	Average.
	From the front slope of a dune.	From the rear slope of a dune.	From the front slope of a dune (a single seam)	
16—8	....	....	....	....
8—4	....	....	....	....
4—2	.2	....	....	tr.
2—1	.0	....	....	....
$1-\frac{1}{2}$	6.2	6.6	1.5	4.7
$\frac{1}{2}-\frac{1}{4}$	34.8	28.2	10.0	24.3
$\frac{1}{4}-\frac{1}{8}$	57.8	61.2	83.0	67.3
$\frac{1}{8}-\frac{1}{16}$	.6	2.7	4.5	2.6
$\frac{1}{16}-\frac{1}{32}$	....	.1	....	tr.
$\frac{1}{32}-\frac{1}{64}$	....	....	....	....
$\frac{1}{64}-\frac{1}{128}$	....	....	....	....
$\frac{1}{128}-\frac{1}{256}$	....	....	....	....

indicating, when compared with the other analyses, the range of variation in the coarseness of the sand due to differences in the velocity of the wind. Evidently this is not very great.

At Folly's Cove in Massachusetts some beach sand is driven inland by the winds. The absence of fine particles in this sand is no doubt partly due to washing on the beach (Tab. VII).

Some sand has been collected from small and freshly formed drifts on plowed fields and on the open prairie in the eastern part of North Dakota. Two samples of this have been placed arbitrarily with the rolling sand, but these differ only slightly from those given here. The rather large amount of dust in all of these analyses is evidently due to the fact that the wind has just begun its work on

Table VII. **Mechanical Composition of Dune Sand from Folly's Cove, Mass.**

Length of diameter in mm.	35	36	Average.
	Dune sand.	Dune sand.	
16—8	....	....	....
8—4	....	....	....
4—2	....	....	....
2—1	....	.1	tr.
$1—\frac{1}{2}$	6.8	4.3	5.5
$\frac{1}{2}—\frac{1}{4}$	27.8	19.0	23.4
$\frac{1}{4}—\frac{1}{8}$	63.8	71.4	67.6
$\frac{1}{8}—\frac{1}{16}$	.7	4.0	2.4
$\frac{1}{16}—\frac{1}{32}$	..... .	.1	tr.
$\frac{1}{32}—\frac{1}{64}$	....	....	....
$\frac{1}{64}—\frac{1}{128}$	....	....	....
$\frac{1}{128}—\frac{1}{256}$	....	....	....

surface deposits, which contain fine materials in some abundance (Tab. VIII).

Scattered dunes occur in the basin of the Green river in Illinois. Though the superficial deposits here are but little affected by the action of the atmosphere now, the topography of several sandy belts in this valley indicates earlier deflation by the atmosphere. The sand is moderately well sorted (Tab. IX).

Table VIII. **Mechanical Composition of Drifting Sand from**

Length of diameter in mm.	37 Field drift in Barnes county.	38 Field drift, Cooperstown, Griggs county.	39 Field drift, Steele county.	40 Drifting sand, Steele county.	41 Drifting sand, Griggs county.
16—8	....	....	....	....	....
8—4	....	....	....	....	....
4—2	....	....	....	....	....
2—1	.2	....	....	....	.1
1—$\frac{1}{2}$	14.5	13.1	6.7	6.4	5.4
$\frac{1}{2}$—$\frac{1}{4}$	28.7	22.7	19.4	14.2	16.8
$\frac{1}{4}$—$\frac{1}{8}$	50.4	55.8	62.3	62.4	63.6
$\frac{1}{8}$—$\frac{1}{16}$	6.1	6.4	9.4	15.6	12.0
$\frac{1}{16}$—$\frac{1}{32}$	1.5	1.3	1.3	1.1	1.2
$\frac{1}{32}$—$\frac{1}{64}$	.3	.2	.3	.2	.3
$\frac{1}{64}$—$\frac{1}{128}$	....	....	....	....	....
$\frac{1}{128}$—$\frac{1}{256}$	....	....	....	....	....

Some years ago a drift of sand was blown up in a field near the city of Lindsborg in the central part of Kansas. The soil in this place was composed of a sandy alluvium, which held very little fine material. No specially noteworthy feature appears in the mechanical composition of this sand (Tab. X).

The most extensive sand-hill region in the United States is probably found in the western part of Nebraska. Here the winds have been at work for a long time rearranging, shifting, and sifting extensive beds, which were formed in Pliocene and early Pleistocene time. Entire counties are covered by extensive ranges of sand hills sometimes exceeding three hundred feet in height. The bulk of the blown sand in this region largely exceeds that of any other locality from which any material has been collected. The lag gravels are conspicuously absent in the samples

North Dakota.

Average.
....
....
....
tr.
9.2
20.3
58.9
9.9
1.3
.3
....
....

Table IX. **Mechanical Composition of Drifting Sand from Green River Valley, Ills.**

Length of diameter in mm.	42 Dune sand from Tampico.	43 Dune sand from Hooppole.	Average.
16—8	....	....	....
8—4	....	....	....
4—2	....	....	....
2—1	.1	....	tr.
$1-\frac{1}{2}$	11.4	2.5	6.9
$\frac{1}{2}-\frac{1}{4}$	32.7	22.1	27.4
$\frac{1}{4}-\frac{1}{8}$	51.4	61.7	56.5
$\frac{1}{8}-\frac{1}{16}$	3.9	14.0	8.9
$\frac{1}{16}-\frac{1}{32}$	....	1.0	.5
$\frac{1}{32}-\frac{1}{64}$	....	....	....
$\frac{1}{64}-\frac{1}{128}$	....	....	....
$\frac{1}{128}-\frac{1}{256}$	....	....	....

examined, nor do these contain more than a trifle of dust. It may be said to be the most uniformly sorted of all the sands described (Tab. XI). Two of the samples (nos. 47 and 48) were selected to represent the extremes of variation among a series of layers which were seen in an exposure with well defined bedding. One was taken from the coarsest seam which could be seen and the other from the finest. The difference in texture was quite apparent to the eye, as the seams appeared

Table X. **Mechanical Composition of Drifting Sand from Lindsborg, Kans.**

Length of diameter in mm.	44 Drifting sand.
16—8	....
8—4	....
4—2	....
2—1	....
$1-\frac{1}{2}$	3.1
$\frac{1}{2}-\frac{1}{4}$	23.3
$\frac{1}{4}-\frac{1}{8}$	69.1
$\frac{1}{8}-\frac{1}{16}$	3.9
$\frac{1}{16}-\frac{1}{32}$	.4
$\frac{1}{32}-\frac{1}{64}$	....
$\frac{1}{64}-\frac{1}{128}$	....
$\frac{1}{128}-\frac{1}{256}$	....

in the natural exposure, but it seems rather insignificant in the analyses.

South of the city of Moline in Illinois there are some drifts of sand in a remnant of an old terrace. It rises like an island in the bottom lands of Rock river. The bulk of the assorted material in this elevated land is quite free from coarse ingredients but there is a considerable admix-

Table XI. **Mechanical Composition of Dune Sand from Western Nebraska.**

Length of diameter in mm.	45	46	47	48	Average.
	Dune sand, Alliance.	Front slope of dune, Alliance.	Coarse seam in dune sand, Hyannis.	Fine seam in dune sand, Hyannis.	
16—8	....	....	....	....	....
8—4	....	....	....	....	....
4—2	....	....	....	....	....
2—1	....	....	....	....	....
$1-\frac{1}{2}$	2.5	1.1	2.8	1.9	4.1
$\frac{1}{2}-\frac{1}{4}$	17.2	16.2	10.2	6.6	12.5
$\frac{1}{4}-\frac{1}{8}$	70.5	80.3	71.3	78.4	75.1
$\frac{1}{8}-\frac{1}{16}$	9.7	1.9	15.3	12.8	9.9
$\frac{1}{16}-\frac{1}{32}$	.1	....	....	....	tr.
$\frac{1}{32}-\frac{1}{64}$	....	....	....	....	....
$\frac{1}{64}-\frac{1}{128}$	....	....	....	....	....
$\frac{1}{128}-\frac{1}{256}$	....	....	....	....	....

ture of fine fragments. Some of these are yet retained, it seems, in the drifting sand, which has not been carried farther than two or three hundred yards (Tab. XII).

In the southern part of Henderson county in Illinois there is a range of sand hills which follow the bluffs of the Mississippi river. In their topographic features these hills resemble sand dunes, but the activity of the winds seems to have come to a standstill at present, except in a

Table XII. **Mechanical Composition of Sand from a small Dune, south of Moline, Ills.**

Length of diameter in mm.	49 From the rear slope of the dune.	50 From the top of the dune.	51 From the top of the dune.	52 Lower front slope of the dune.
16—8	......	......	......	......
8—4	......	......	......	......
4—2	......	......	......	......
2—1	......	......	......	......
1—$\frac{1}{2}$	2.6	3.2	3.7	2.2
$\frac{1}{2}$—$\frac{1}{4}$	24.3	15.6	15.9	14.7
$\frac{1}{4}$—$\frac{1}{8}$	68.1	72.0	65.7	66.9
$\frac{1}{8}$—$\frac{1}{16}$	10.7	7.2	12.0	12.8
$\frac{1}{16}$—$\frac{1}{32}$	2.7	3.0	2.0	2.4
$\frac{1}{32}$—$\frac{1}{64}$	.2	......	.3	.3
$\frac{1}{64}$—$\frac{1}{128}$	......	......	......	......
$\frac{1}{128}$—$\frac{1}{256}$	......	......	......	......

Table XII. (**Continued.**)

53 Top of the dune.	54 Upper front slope of the dune.	55 Top of the dune.	56 Lower front slope of the dune.	Average.
......	......	......	......	......
......	......	......	......	......
......	......	......	......	......
......	......	......	......	......
.7	1.2	2.1	.9	2.1
12.9	11.0	10.7	10.0	14.0
74.6	73.9	71.9	66.0	69.9
10.6	12.4	12.5	23.7	12.7
.6	.6	3.1	.5	1.5
......	......	.2	......	.1
......	......	......	......	......
......	......	......	......	......

few places on the summits of the ridges (Tab. XIII). Two samples from this locality show a remarkably perfect sorting, though one of them (no. 58), which was taken from a drifting cultivated field, carries the usual quantity of fine grades present in drifting soils.

It will be noticed that in all these samples of dune sand, excepting the one collected by skimming the ridge

Table XIII. **Mechanical Composition of Blown Sand from Henderson County, Ills.**

Length of diameter in mm.	57 From a dune on the bluff east of Carman.	58 From a field near Decorra.	Average.
16—8	....	....	....
8—4	....	....	....
4—2	....	....	....
2—1	....	....	....
$1-\frac{1}{2}$	1.2	.2	.7
$\frac{1}{2}-\frac{1}{4}$	5.4	1.7	3.5
$\frac{1}{4}-\frac{1}{8}$	84.6	81.4	83.0
$\frac{1}{8}-\frac{1}{16}$	8.6	8.0	8.3
$\frac{1}{16}-\frac{1}{32}$	.2	5.0	2.6
$\frac{1}{32}-\frac{1}{64}$	....	2.0	1.0
$\frac{1}{64}-\frac{1}{128}$	....	....	....
$\frac{1}{128}-\frac{1}{256}$	....	....	....

of a ripple, the maximum ingredient is fine sand. In one instance ninety-two per cent consists of this grade, while in three cases it forms over eighty per cent of the bulk. Where lowest it forms forty-five per cent, and it averages sixty-five per cent in all the sand examined (Tab. XIV). In three of the samples ninety per cent is distributed among four grades; in twenty-two, among three grades; and in thirteen, between only two. Here also the admix-

tures arrange themselves in two series decreasing on either side of the maximum. The coarse admixtures form a less rapidly decreasing series than the fine, the former extending over five grades in the general average and the latter over only three grades. The extension of either is diminished by prolonged wind action, which results in more perfect elimination of grains near either extreme.

Table XIV. **General Average of the Composition of Dune Sand (based on the averages for each locality where samples have been taken).**

Length of diameter in mm.	Average.
16—8	....
8—4	tr.
4—2	.2
2—1	1.3
$1-\frac{1}{2}$	5.9
$\frac{1}{2}-\frac{1}{4}$	20.8
$\frac{1}{4}-\frac{1}{8}$	65.1
$\frac{1}{8}-\frac{1}{16}$	6.2
$\frac{1}{16}-\frac{1}{32}$	.6
$\frac{1}{32}-\frac{1}{64}$	.1
$\frac{1}{64}-\frac{1}{128}$	....
$\frac{1}{128}-\frac{1}{256}$	....

The occurrence of the maximum at the same or nearly the same point in nearly all the dune sand taken at many different localities, challenges our special notice. The size of a particle capable of being transported by the current of a fluid varies as the sixth power of the velocity of the current. The diameter of the particles, therefore, varies as the square of the velocity. If the velocity is doubled, the diameter of particles transported may be increased four times. The range of velocities of dune-making winds, as usually measured, certainly exceed a doubling of their speed, and it might be expected that the bulk of the sand, in some place at least, should consist of grains many times as large as in others. It may be that sometimes there is a scarcity of such sand for the wind to work on, but this will not alone account for the uniform composition of the dune sand. Wind velocities are usually measured some

distance above the ground, but the dune sand is moved only by the very lowest layer in the atmosphere. Now it is known that the velocity of the current in this lowermost layer is increased at a very slow rate with an increase in the speed of the layers next above it. The velocity in the layer next to the surface of the ground probably never reaches three miles per hour. It is this comparatively inert layer, which alone comes in contact with the resting sand and first causes it to stir. As velocities much lower than this will not move sand at all, the range of variation of the velocity of the currents which impel dune sand, is most likely quite limited. Another circumstance aids in bringing about the same result. Any load which is picked up, has the effect of retarding the current in which it is carried and the greater the particle which is moved, the greater the retardation will be. In an element of such lightness as the air this retardation must be considerable.

Another significant feature in the analyses of the dune sand is the more rapid decrease in the percentages of the finer grades than in the percentages of the coarser grades, in the opposite direction. Evidently the law which governs the separation of the fine admixtures from the dune sand is different from the law which determines the separation of the latter from the coarse admixtures. A little reflection makes this clear. Materials finer than dune sand are wholly lifted up into swifter currents, which promptly remove them. The dune sand itself, on the other hand, is partly lifted and also partly rolled, just as the grains of the nearest larger sizes. Working in this last manner the transporting power of the wind varies

more nearly in approximation to its erosive force than to its lifting force. With changes in velocities the latter varies as the sixth power, while the erosive force varies as the square. It is therefore much easier for the coarser ingredients to be rolled along with the dune sand than it is for the dune sand to be picked up and carried away with the finer ingredients. The wind much more rapidly

Table XV. **Mechanical Composition of Sand heaped up by Incipient Drifting.**

Length of diameter in mm.	59 From a drifting field, Kansas.	60 On a snow drift in Maryland.	61 From a gutter in Baltimore, Md.	62 Beach, St. Augustine, Fla.	63 Road-bed, Carman, Ills.
16—8	....	....	....	....	....
8—4	....	....	....	....	....
4—2	....	....	....	....	....
2—1	....	.1	....	....	....
$1-\frac{1}{2}$	.3	5.7	.6	tr.	16.8
$\frac{1}{2}-\frac{1}{4}$	5.7	36.3	2.6	.3	29.6
$\frac{1}{4}-\frac{1}{8}$	60.3	53.5	50.2	97.0	51.4
$\frac{1}{8}-\frac{1}{16}$	29.9	2.6	44.6	2.9	.8
$\frac{1}{16}-\frac{1}{32}$	2.8	1.0	1.4	....	tr.
$\frac{1}{32}-\frac{1}{64}$	.5	....	.5	....	....
$\frac{1}{64}-\frac{1}{128}$	....	....	tr.	....	....
$\frac{1}{128}-\frac{1}{256}$	....	....	....	....	....

ceases to lift sand grains exceeding one eigth of a millimeter in diameter than it ceases to roll grains which become larger than one fourth of a millimeter. The operation of this principle is more or less evident in all the samples, but it is best seen in such as have been taken from the surface of the highest ridge and the rear slope of a dune. It is most conspicuous in the general average of the averages of the sands from each locality.

Though it is not supposed that all dune sand is as uniform in composition as are the specimens described here, it seems probable that the wind forms drifts mainly of grains which measure from one half to one eight of a millimeter in diameter. How promptly it selects just these sizes for drift-building, may be seen in the composition of some specimens of sand collected from widely distant places, where it has just begun to work on materials of quite diversified composition (Tab. XV). In the following table one sample (no. 59) was collected in Kansas in a bottle placed about a foot above the ground in a drifting cultivated field, where the soil held gravel as well as clay; one (no. 60) was taken from the surface of a snow-drift in Maryland, where the deposit had blown from an exposure of Potomac sand of somewhat heterogenous composition; one (no. 61) is from a gutter in the city of Baltimore and was sifted out by the wind from the dust on a paved street; one (no. 62) is from the beach at St. Augustine in Florida where such sand is reported to be tossed about by the sporting wind with particular ease, owing to the fact that the water has already affected a most favorable sorting; and one (no. 63) was collected in a small receptacle placed on a drifting railroad bed in the western part of Illinois. The chief ingredient in these sands is alike in all and is of the same grade as that found in dune sand.

LEE SAND.

We have now to see what becomes of the rock fragments that are finer than the maximum grade of the dune sand, a small part of which only are retained in the drifts. Right in the front of the dune drift, and confluent with it, there is generally a smaller rippleless drift or bench of

Table XVI. **Mechanical Composition of Sand taken in the Lee of Sand Dunes In Rice co., Kansas.**

Length of diameter in mm.	Average of the dune sand.	64	65	66	67
		Lee drift sand.	From six feet in front of the lee drift.	From 15 feet in front of the lee drift.	From 24 feet in front of the lee drift
16—8	....	....	....	....	....
8—4	....	....	....	....	....
4—2	....	....	....	....	....
2—1	....	....	....	....	....
$1-\frac{1}{2}$	4.7	2.1	.2	.3	....
$\frac{1}{2}-\frac{1}{4}$	24.3	16.5	4.6	1.5	1.1
$\frac{1}{4}-\frac{1}{8}$	67.3	72.0	60.0	72.3	62.0
$\frac{1}{8}-\frac{1}{16}$	2.6	7.5	31.0	23.8	32.1
$\frac{1}{16}-\frac{1}{32}$	tr.	....	.7	2.1	3.4
$\frac{1}{32}-\frac{1}{64}$	....	....	....	....	.6
$\frac{1}{64}-\frac{1}{128}$	....	....	....	....	....
$\frac{1}{128}-\frac{1}{256}$	....	....	....	....	....

sand, which has settled in the eddy in the lee of the larger drift.*) The sand in the lee drift, as it may be called, is found to be a little finer than the dune sand proper. Its grains have been lifted a little higher, and that is the reason why they have been carried a little farther. But the difference is very slight and consists merely in a

*) See Die Denudation in der Wüste etc., Johames Walther, p. 172, fig. 89.

change in the proportions of the percentages on either side of the maximum.

It is evident that the finer grains, which may have been present originally or which may have been produced by trituration afterwards, are carried still farther away. Just how far each different grade may be carried from the place where it is first taken up in the wind, has not been made out satisfactorily, but there can be no doubt that the different grades in the fine material are let down at successively greater distances according to their coarseness. Some inferences with regard to these distances may however be drawn from the examination of some sediments, which the writer has taken occasion to collect somewhat promiscuously.

Four series of wind sediments have been taken from successively more distant points in front of dunes and sand drifts in Kansas, Illinois and North Dakota. The analyses of these series show that the grains which approximate nearest to the dune sand in size are not carried very far. The samples from Rice county in Kansas and those taken near Moline in Illinois exhibit merely a decrease of the coarse admixtures and a corresponding increase in the fine for increasing distances within a range of two hundred feet (Tab. XVI and XVII).

The maximum ingredient still consists of fine sand. While this rate of change is not very rapid, it is such as to indicate that the maximum ingredient in the drift sediments in this direction would change to very fine sand a few hundred feet farther out.

In distances less than two hundred feet the percentage of the fine ingredients increases from eight in the dune

Table XVII. **Mechanical Composition of Sand taken in the Lee of Drifting Sand south of Moline, Ills.**

Length of diameter in mm.	Average of the dune sand.	71 10 feet in front of the dune.	72 100 feet in front of the dune.	73 160 feet in front of the dune.
16—8	....	....	....	....
8—4	....	....	....	....
4—2	....	....	....	....
2—1	....	....	....	....
$1-\frac{1}{2}$	2.1	....	....	....
$\frac{1}{2}-\frac{1}{4}$	14.0	4.2	2.6	1.9
$\frac{1}{4}-\frac{1}{8}$	69.9	55.6	58.5	51.8
$\frac{1}{8}-\frac{1}{16}$	12.7	34.0	28.8	32.0
$\frac{1}{16}-\frac{1}{32}$	1.5	5.6	9.0	13.7
$\frac{1}{32}-\frac{1}{64}$	.1	.3	.4	.3
$\frac{1}{64}-\frac{1}{128}$	....	....	....	....
$\frac{1}{128}-\frac{1}{256}$	....	....	....	....

Table XVIII. **Mechanical Composition of Sand taken in the Lee of Drifting Fields in North Dakota.**

Length of diameter in mm.	Average of drift sand.	74 Dust in a house 4 mi. from a drifting field.	75 Dust in a school-house, 4 mi. from a drifting field.
16—8	....	....	....
8—4	....	....	....
4—2	....	....	....
2—1	tr.	....	.1
$1-\frac{1}{2}$	9.2	.5	.4
$\frac{1}{2}-\frac{1}{4}$	20.3	1.0	.3
$\frac{1}{4}-\frac{1}{8}$	58.9	5.0	4.6
$\frac{1}{8}-\frac{1}{16}$	9.9	19.8	22.8
$\frac{1}{16}-\frac{1}{32}$	1.3	58.9	60.9
$\frac{1}{32}-\frac{1}{64}$	.3	12.7	9.4
$\frac{1}{64}-\frac{1}{128}$	....	1.3	.7
$\frac{1}{128}-\frac{1}{256}$	....	tr.	tr.

sand to forty-one in the lee-sand. The series taken in front of the sand drift at Lindsborg changes more rapidly, so that only fifty feet away sixty-five parts in a hundred consist of very fine sand (Tab. XIX).

The dune at this place was much lower than the other, and this partly accounts for the more rapid settling of the fine sand, which here had a much shorter distance to

Fig. XIX. **Mechanical Composition of some Sand taken in the Lee of Drifting Sand near Lindsborg, Kans.**

Length of diameter in mm.	Dune sand.	68 Lee drift sand.	69 Sand from 10 feet in front of lee drift.	70 Sand from 50 feet in front of lee drift.
16—8	....	....	....	....
8—4	....	....	....	....
4—2	....	....	....	....
2—1	....	....	....	....
$1-\frac{1}{2}$	3.1	3.2	.6	.7
$\frac{1}{2}-\frac{1}{4}$	23.3	18.7	3.3	1.3
$\frac{1}{4}-\frac{1}{8}$	69.1	71.2	69.3	14.4
$\frac{1}{8}-\frac{1}{16}$	3 9	5.0	20.5	65.2
$\frac{1}{16}-\frac{1}{32}$	.4	3.9	5.9	16.3
$\frac{1}{32}-\frac{1}{64}$	....	.1	.3	.8
$\frac{1}{64}-\frac{1}{128}$	....	....	....	....
$\frac{1}{128}-\frac{1}{256}$	....	....	....	....

fall. The samples from North Dakota were taken in buildings and are not strictly comparable to the other, but the small amount of fine sand and even of very fine sand which they contain, indicates that most of the former grade, at any rate, had already settled (Tab. XVIII).

As the houses were about four miles away from the place of active drifting, it seems safe to infer that this

distance exceeds that over which fine sand is generally lifted in single leaps. And this quite likely also applies to the transportation of the next finer grade. It should also be noticed here that only a very subordinate percentage of particles smaller than one thirty-second of a millimeter in diameter settles within the distance observed.

We may infer that the grades of rock fragments which range in diameter from one eigth to one sixteenth of a millimeter in diameter are mainly deposited, together with some coarser and some finer ones, in front of drifting tracts as a thin apron, which becomes finer in composition with increasing distance to the leeward. There is little doubt that the change in the texture of this apron deposit is most rapid at first and more slow farther out. Its deposition results from temporary lulls in the wind, which allow the coarser grains to fall to the ground. Going down the scale of diminishing particles a size will at last be found, which is capable of almost indefinite suspension in the changeable currents of the atmosphere. Material of this kind is scattered over wide distances and the change in the texture of the deposits formed from this dust progresses with extreme slowness from one place to another.

ATMOSPHERIC DUST.

To determine the size of the particles that may readily be transported such long distances by ordinary winds, it is only needed to examine the nature of the loads which these winds generally carry. I have collected a number of samples of such dust by different methods, under dif-

Table XX. **Mechanical Composition of some Dust collected in Running Railroad Coaches.**

Length of diameter in mm.	76 Sandstorm in Arizona.	77 From southern Minnesota.	78 From Nebraska and Kansas.	79 From New England.
16—8	....	....	....	....
8—4	....	....	....	....
4—2	....	....	....	....
2—1	....	....	....	....
1—$\frac{1}{2}$	.3	....	tr.	.2
$\frac{1}{2}$—$\frac{1}{4}$	.6	1.0	.5	1.3
$\frac{1}{4}$—$\frac{1}{8}$	17.0	14.0	12.0	12.0
$\frac{1}{8}$—$\frac{1}{16}$	44.5	32.8	17.2	32.0
$\frac{1}{16}$—$\frac{1}{32}$	29.2	41.0	52.6	49.0
$\frac{1}{32}$—$\frac{1}{64}$	5.5	9.8	12.5	4.0
$\frac{1}{64}$—$\frac{1}{128}$	.6	1.2	1.3	.5
$\frac{1}{128}$—$\frac{1}{256}$	....	....	....	....

Table XX. **(Continued).**

80 From N. Dakota and Montana.	81 From Rocky Mts. and Cascade Mts.	82 From Utah. Speed 30 mi. pr h.	83 From N. Dakota, after a storm.	84 From N. Dakota.
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....
1.0	....	tr.	tr.	tr.
4.0	3.4	11.0	3.5	3.6
15.8	19.0	67.2	49.1	35.5
29.7	34.0	19.7	39.7	56.8
38.1	29.0	1.7	7.0	3.9
11.9	9.1	tr.	.9	tr.
1.4	2.0	....	....	....

ferent conditions of deposition, and from different localities.

Before discussing the composition of these samples it may, however, be well to note the nature of some windborne sediments which have been carried by the atmosphere under more than ordinarily favorable circumstances, and in currents of more than ordinary strength. Such is the sand and dust stirred up from the roadbeds by running railroad trains. Quartz particles considerably larger than fine sand are here moved nearest the ground. But the material which is lifted high enough (five or six feet) to come in through the windows and doors of passenger coaches is much finer.

Among thirteen samples of such material collected in coaches in different parts of the United States only one

Table XX. (**Continued**).

85	86	87	88	
From Western Minnesota.	From Eastern Colorado.	From Kansas.	From Idaho and Washington.	Average.
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....
....	....	....	....	tr.
....	....	.1	....	.3
2.0	1.0	.6	.3	6.4
49.0	22.8	36.8	54.8	36.6
43.1	65.2	57.0	41.6	42.9
4.9	10.2	4.6	3.3	10.3
.5	.5	.5	.1	2.9
....	....	....	....	.2

had as much as seventeen per cent of fine sand, and one had less than one per cent (Tab. XX). In five of these samples the maximum occurs in the grade of very fine sand, which is next in fineness to the maximum grade of the dune sand; in seven of the samples it occurs in the coarse dust; and in one it is in the next finer grade. The small percentages of the coarser grains is no doubt in part due to the reduced velocities of the currents entering the coaches. Analogous causes may have affected the perfection of the sorting in these samples, which varies considerably, ninety parts in a hundred being distributed among four grades in some instances and between only two in some. But the differences in the speed of the trains and the differences in the mechanical composition of the surface deposits along the railroads must also be taken into account. Nor was the sampling uniform. In some instances the dust was taken after heavy winds and in others during calm weather, sometimes it was gathered up from the window sills and sometimes from the seats in the coaches. Some of it was brushed from the wearing apparel of a passenger. Taking all these modifying circumstances into due consideration and remembering that the currents of wind which follow a running railroad train are quite as powerful as the cur-

Table XXI. **Mechanical Composition of some Dust taken from a Window Sill in a House in Yuma, Arizona.**

Length of diameter in mm.	89
16—8	....
8—4	....
4—2	....
2—1	....
$1-\frac{1}{2}$	.3
$\frac{1}{2}-\frac{1}{4}$	.6
$\frac{1}{4}-\frac{1}{8}$	7.3
$\frac{1}{8}-\frac{1}{16}$	46.5
$\frac{1}{16}-\frac{1}{32}$	36.4
$\frac{1}{32}-\frac{1}{64}$	7.0
$\frac{1}{64}-\frac{1}{128}$	.8
$\frac{1}{128}-\frac{1}{256}$	tr.

rents next to the ground in the heaviest wind storm, the composition of this dust may be said to indicate that fine sand is too heavy to be effectively kept from settling in such winds, that very fine sand and coarse dust are just on the limits of the size which is subject to effective suspension, and that particles which have a diameter less than one thirty-second of a millimeter will not readily settle from the atmosphere in a strong wind. It may be inferred also that dust of the kind taken in railway coaches must be capable of being lifted up into the atmosphere by moderately strong winds. This is also indicated by the composition of some dust gathered on a window sill three feet above the ground in a building at Yuma in Arizona (Tab. XXI).

Volcanic dust forms another class of atmospheric sediments which are transported under unusually favorable conditions. It is launched from great heights, to which it never could have been raised by the convection currents of the lower part of the atmosphere, and it is carried by the upper currents, where transportation is much more swift than below. Nearest the volcanic outburst there is no maximum limit to the size of volcanic fragments which may fall, but beyond the distance of the influence of the projectile force, which seldom, perhaps, exceeds a dozen miles, their size is determined by the sorting action of atmospheric currents and hence will be a true exponent of the nature of this action.

Seven samples of such volcanic dust have been examined (Tab. XXII). Five of these are from quaternary deposits on the western plains, one is from the Lahontan sediments in Nevada, and one is from a recent shower on

Table XXII. **Mechanical Composition of Volcanic Dust.**

Length of diameter in mm.	90 From a coarse layer, McPherson co., Kans.	91 From McPherson co., Kans.	92 From Golden, Colo.	93 From snow in Norway.
16—8	....	....	....	....
8—4	....	....	....	....
4—2	....	....	....	....
2—1	....	....	....	....
$1—\frac{1}{2}$	tr.	....	.5	....
$\frac{1}{2}—\frac{1}{4}$	.5	.2	.8	tr.
$\frac{1}{4}—\frac{1}{8}$	46.0	28.8	37.4	10.0
$\frac{1}{8}—\frac{1}{16}$	52.0	24.8	36.4	42.0
$\frac{1}{16}—\frac{1}{32}$	1.0	33.4	21.7	42.0
$\frac{1}{32}—\frac{1}{64}$	....	11.1	1.6	5.2
$\frac{1}{64}—\frac{1}{128}$	....	1.2	.2	.7
$\frac{1}{128}—\frac{1}{256}$	....	.2	....	....

Table XXII. (**Continued.**)

94 From Furnas co., Nebr.	95 From Nevada.	96 From Orleans, Nebr.	Average.
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....
.2	tr.	....	.1
.1	tr.	....	.1
7.0	2.4	.2	18.8
51.0	32.4	19.4	36.8
37.2	40.1	51.0	32.3
3.4	20.2	23.4	9.2
.2	5.4	5.2	1.8
....	.6	.2	.1

the coast of Norway, following an eruption in Iceland. The coarsest one forms the bottom layer in a deposit in Kansas, where the material settled in water. It contains only the coarsest fragments, which first settled on the bottom under the water. The other sample from the same place represents more nearly the average of the same shower at that place. The dust from Golden in Colorado is the second in coarseness. It fell nearer the place of the eruption, which propably was somewhere in Colorado. The Norway dust which was carried a distance of eight hundred miles, is of about average fineness, compared with the other samples. The materials from Nebraska and Nevada are finer. The variation in composition is quite remarkable in these samples, but it is largely due to secondary sorting in water.

On comparing the average of these analyses with that of sand and dust taken in coaches, the latter are seen to be slightly finer. This appears hardly possible, when we think of the great distances the volcanic dust has been carried, but there are three circumstances which combine to keep the volcanic dust in suspension longer than any other atmospheric sediments. Most of its particles are in the form of flakes, tubes, or hollow bubbles. The flakes may be twenty times as long and as wide, as thick. Such material floats easily in the air. Besides, other sediments have first to be raised by the lower and weaker currents of the air, as already pointed out, while the volcanic dust is thrown up to great heights by an explosion. And then the dust itself is about one fifth lighter than ordinary quarts. We must hence infer that ordinary dust, which is capable of being transported several hundred miles by

the atmosphere, is finer than volcanic dust, most of which consists of particles ranging from one eigth to one thirty-second of a millimeter in diameter.

Somewhat similar inferences may also be made from the nature of some dust taken close to wagon roads, where it was raised by passing vehicles and sifted as it fell by gentle winds. In some dust of this kind, which fell

Table XXIII. **Mechanical Composition of Dust collected close to a travelled Wagon Road.**

Length of diameter in mm.	97 Dust taken 5 ft. from a road near Baltimore, Md.	98 Dust taken 15 ft. from a road near Baltimore, Md.	99 Dust taken 25 ft. from a road near Rock Island, Ills.	100 Dust taken 25 ft. from a road near Baltimore, Md.	Average.
16—8	....	....	....	....	....
8—4	....	....	....	....	....
4—2	....	....	....	....	....
2—1	.4	....	....	....	.1
1—$\frac{1}{2}$	4.0	.2	... ..	.7	1.2
$\frac{1}{2}$—$\frac{1}{4}$	6.7	.8	tr.	.7	2.0
$\frac{1}{4}$—$\frac{1}{8}$	23.7	3.5	1.4	3.0	7.9
$\frac{1}{8}$—$\frac{1}{16}$	26.1	31.3	29.2	9.6	24.0
$\frac{1}{16}$—$\frac{1}{32}$	25.0	48.6	45.1	58.0	44.2
$\frac{1}{32}$—$\frac{1}{64}$	9.2	14.8	23.1	21.7	17.2
$\frac{1}{64}$—$\frac{1}{128}$	4.3	.7	.5	4.2	2.4
$\frac{1}{128}$—$\frac{1}{256}$	.6	.1	....	.6	.3

five feet from the road, twenty-three per cent was fine sand and eleven per cent cwas omposed of still coarser grains (Tab. XXIII). In some other dust, which fell ten feet farther away, there was only a little over four per cent of the coarse grades. In this sample very fine sand forms thirty-one per cent. Ten feet still farther out this grade is represented by less than ten per cent. These grades evidently easily settle out of gentle atmospheric currents.

Of particles which are less than one sixty-fourth of a millimeter in diameter, there are only small quantities, presumably because such particles tardily settle even in ordinary low winds.

Some dust which was swept by the wind from the banks and the bottom lands of the Minnesota river and lodged on the ice in its channel close by, shows about the same composition as the average of the last samples (Tab. XXIV).

Table XXIV. **Mechanical Composition of Dust taken on the Ice in the Minnesota River.**

Length of diameter in mm.	101
16—8	....
8—4	....
4—2	....
2—1	....
$1-\frac{1}{2}$	tr.
$\frac{1}{2}-\frac{1}{4}$	.6
$\frac{1}{4}-\frac{1}{8}$	6.1
$\frac{1}{8}-\frac{1}{16}$	16.6
$\frac{1}{16}-\frac{1}{32}$	53.4
$\frac{1}{32}-\frac{1}{64}$	20.7
$\frac{1}{64}-\frac{1}{128}$	1.0
$\frac{1}{128}-\frac{1}{256}$	....

The dust from the railroad coaches, the volcanic dust, the dust from the wagon roads, and this last sample from the ice of the Minnesota river may be said to indicate that particles, which are capable of suspension in strong winds, must have a diameter less than one sixteenth of a millimeter in length, and that particles with a diameter of less than one fourth of this length are hindered from promptly settling out of such winds. The latter part of this statement must however be made with a limitation as to the quantity of the load which is carried. Should this be increased beyond a certain limit, flocculation will take place, and then even finer dust will soon be brought down.

Fifty-six samples of dust capable of prolonged suspension in the atmosphere have been studied, and will here be described under three divisions: 1) dust collected

directly from the atmosphere by means of some apparatus; 2) dust which has settled out of the atmosphere on surfaces more or less elevated above the ground, as from leaves of trees and from house-roofs, and 3) dust which has settled out of the atmosphere on snow, on ice, or on other surfaces nearly on a level with the ground.

DUST COLLECTED DIRECTLY FROM THE ATMOSPHERE.

One of the devices used in collecting dust directly from the atmosphere consisted of some whisks of broom-corn, smeared with glycerine, and suspended from a pole ninety feet above the ground. The observations were made on a bluff overlooking the Mississippi river at Rock Island

Table XXV. **Mechanical Composition of Dust collected directly from the Atmosphere by means of Whisks of Broom-corn smeared with Glycerine, March, 1895.** *)

Length of diameter in mm.	102	103	104	105
	Maximum hourly velocity, 12 miles.	Maximum hourly velocity, 17 miles.	Maximum hourly velocity, 22 miles.	Maximum hourly velocity, 28 miles.
16—8	....	....	....	....
8—4	....	....	....	....
4—2	....	....	....	....
2—1	....	....	....	....
$1-\frac{1}{2}$	....	....	....	....
$\frac{1}{2}-\frac{1}{4}$	....	....	....	....
$\frac{1}{4}-\frac{1}{8}$	....	....	....	....
$\frac{1}{8}-\frac{1}{16}$	16.9	3.0	14.8	12.0
$\frac{1}{16}-\frac{1}{32}$	22.5	16.2	18.5	15.0
$\frac{1}{32}-\frac{1}{64}$	38.3	43.3	37.1	49.5
$\frac{1}{64}-\frac{1}{128}$	19.7	34.7	25.9	21.0
$\frac{1}{128}-\frac{1}{256}$	2.2	2.6	3.3	2.2

*) The method used in making the analyses given in this table was somewhat imperfect and the proportions of particles ranging in size from a diam. of $\frac{1}{8}$ to $\frac{1}{16}$ of a millimeter is too large.

in Illinois. The whisks were taken down once a day and washed in water which was allowed to stand until the dust had settled. This was then removed, dried, and ignited. One series of such samples was secured during the month of March in 1895. These ware taken daily and mixed into five larger samples, each of which represented days with maximum hourly wind velocities ranging between certain limits as indicated in the table of analyses. The range of these velocities during the month was from twelve to thirty-three miles per hour, and the quantities of dust taken were quite proportionate to the sixth power of these velocities, ranging from one tenth of a gram to fifty grams. The analyses do not indicate that there was any decided increase in the size of the particles transported during the days having the strongest wind, as might have been expected (Tab. XXV). The maximum in each of the samples occurs in the medium dust and the samples taken on the calmest days appear to contain the largest proportion of coarse admixtures. There is, however, a small decrease of the fine admixtures in the dust taken during the most windy day, when the highest hourly velocity was thirty-three miles.

Table XXV. **(Continued).**

106 Maximum hourly velocity, 33 miles.	Average.
....	....
....	....
....	....
....	....
....	....
....	....
tr.	tr.
14.2	12.2
21.3	18.7
50.5	43.7
12.4	22.7
1.0	2.2

In June the same year material was collected in the same way and at the same place, daily, for one week, and a separate analysis

Table XXVI. **Mechanical Composition of Dust collected directly from the Atmosphere by means of Whisks of Broom-corn smeared with Glycerine, June 16—22, 1895.**

Length of diameter in mm.	107 Maximum hourly velocity, 9 miles.	108 Maximum hourly veloc.ty 9 miles.	109 Maximum hourly velocity, 12 miles.	110 Maximum hourly velocity, 13 miles.
16—8	....	....	....	....
8—4	....	....	....	....
4—2	....	....	....	....
2—1	....	....	....	....
$1-\frac{1}{2}$	....	....	....	....
$\frac{1}{2}-\frac{1}{4}$	....	....	....	....
$\frac{1}{4}-\frac{1}{8}$	tr.	tr.	tr.	tr.
$\frac{1}{8}-\frac{1}{16}$	6.0	3.0	3.0	2.0
$\frac{1}{16}-\frac{1}{32}$	37.6	32.4	44.0	35.0
$\frac{1}{32}-\frac{1}{64}$	43.9	43.0	44.0	40.0
$\frac{1}{64}-\frac{1}{128}$	10.3	19.0	7.0	19.1
$\frac{1}{128}-\frac{1}{256}$	1.0	1.0	.4	1.2

Table XXVI. **(Continued.)**

111 Maximum hourly velocity, 19 miles.	112 Maximum hourly velocity 22 miles.	113 Maximum hourly velocity, 22 miles.	Average.
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....
tr.	....	tr.	tr.
5.7	1.1	2.7	3.3
22.9	23.5	27.3	31.9
50.2	45.9	49.1	45.1
20.0	26.7	19.1	17.3
2.2	2.3	.9	1.3

was made of each catch. The maximum hourly velocities of the wind for each day ranged from nine to twenty miles. In this case also there was a correspondence between the wind velocities and the quantities of the dust caught, but on examining the analyses, it it seen that the coarse admixtures rather decrease than increase with the speed of the wind. The fine ingredients are quite as

Table XXVII. **Mechanical Composition of Dust collected directly from the Atmosphere by means of Muslin, smeared with Glycerine, July, Aug. Sept., 1895.**

Length of diameter in mm.	114	115	116	117	Average.
	From the flagpole during June and July, 1895.	Under trees in a grove.	Top cloth on flag-pole, Aug. 19, 1895.	Bottom cloth on flag pole, Aug. 19, 1895.	
16—8	....	....	....	....	....
8—4	....	....	....	....	....
4—2	....	....	....	....	....
2—1	....	....	....	....	....
$1—\frac{1}{2}$	....	....	....	....	....
$\frac{1}{2}—\frac{1}{4}$	tr.	....	....	....	tr.
$\frac{1}{4}—\frac{1}{8}$	.3	tr.	tr.	tr.	tr.
$\frac{1}{8}—\frac{1}{16}$	9.0	4.9	3.9	1.0	4.7
$\frac{1}{16}—\frac{1}{32}$	32.0	40.7	19.0	24.6	29.1
$\frac{1}{32}—\frac{1}{64}$	43.9	41.5	47.2	45.1	44.4
$\frac{1}{64}—\frac{1}{128}$	11.3	11.5	26.6	28.7	19.5
$\frac{1}{128}—\frac{1}{256}$	1.6	.9	3.0	1.1	1.7

well represented for the days with high winds as for days with low winds (Tab. XXVI).

Some dust was collected at the same place and at the same height by suspending two pieces of muslin held horizontally on a frame. The muslin was smeared with glycerine, to which the dust adhered. This was secured by washing and allowed to settle as before. One sample

consisted of a mixture of daily catches taken during part of June and part of July in 1895. These were thoroughly mixed before the analysis was made. Two samples which were taken, one on the upper cloth and one on the lower, on the nineteenth of August the same year, were separately examined, as was also some other material collected in the same manner under some trees in a grove about a quarter of a mile from the pole previously referred to. The dust taken in this way resembles perfectly that which was caught on the broom-corn. The percentages of the several grades correspond almost to within two percent in the two averages (Tab. XXVII).

It will be noticed that the composition of the mixed sample for June and July is very much like the average for the dust taken on the broom-corn in June, but it is somewhat coarser than that taken on muslin in August. The dust taken under the trees in the grove is also a little coarser than the latter.

Another devise for collecting dust from the atmosphere consisted of a hollow cylinder, with apertures on the side for receiving the wind, and with strips of muslin suspended inside. These strips as well as the inner surface of the cylinder were washed once a week, and adhering particles thus secured. Eight samples were taken by this method during the months of July, August and September in 1895 (Tab. XXVIII)). The cylinder was suspended at the same height and from the same flag pole as the broom-corn and the muslin previously mentioned. In this series of samples, also, there was a correspondence between the wind velocities and the quantities of dust caught, though not so well marked as in the other in-

Table XXVIII. **Mechanical Composition of Dust collected directly from the Atmosphere by Means of Slack Wind in a hollow Cylinder, July, Aug., and Sept., 1895.**

Length of diameter in mm.	118 Maximum hourly velocity, 14 miles.	119 Maximum hourly velocity 18 miles.	120 Maximum hourly velocity, 18 miles.	121 Maximum hourly velocity, 19 miles.
16—8	....	....	....	....
8—4	....	....	....	....
4—2	....	....	....	....
2—1	....	....	....	....
$1-\frac{1}{2}$	....	....	....	....
$\frac{1}{2}-\frac{1}{4}$	....	....	....	....
$\frac{1}{4}-\frac{1}{8}$	.5	1.0	1.0	5.0
$\frac{1}{8}-\frac{1}{16}$	11.1	32.0	18.7	20.0
$\frac{1}{16}-\frac{1}{32}$	33.4	40.0	51.4	44.5
$\frac{1}{32}-\frac{1}{64}$	40.1	17.7	19.8	21.1
$\frac{1}{64}-\frac{1}{128}$	13.3	7.5	8.2	7.3
$\frac{1}{128}-\frac{1}{256}$	1.6	1.6	.6	1.2

Table XXVIII. **(Continued).**

122 Maximum hourly velocity, 20 miles.	123 Maximum hourly velocity 21 miles.	124 Maximum hourly velocity, 23 miles.	125 Maximum hourly velocity, 24 miles.	Average.
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....
tr.	1.0	....	....	1.0
6.8	18.7	8.5	9.5	15.6
47.6	51.4	52.9	38.1	44.9
35.4	19.8	27.4	34.9	27.0
9.5	8.2	10.2	15.9	10.0
.2	.6	.2	1.2	.9

stances referred to. On the nineteenth of February in 1896, when there was a high wind and much dust in the atmosphere over the Mississippi valley, one more sample was taken in the cylinder, this time suspended only ten feet above the ground (Tab. XXIX).

All of the dust caught in the cylinder, excepting two samples, is coarser than that which was caught on adhesive surfaces. The maximum grade consists of coarse dust in the former, while in the latter it is medium dust. It appears that the slack wind was not retained in the cylinder long enough to allow the fine particles to settle. In this way the maximum has been transferred toward the coarse grades. If then, as we may suppose, the dust carried by the air was of the same average composition in both instances, the rate of decrease from grade to grade on either side of the maximum ought to be more nearly equal in the dust caught in slack wind. Such is also the case, as may be seen from the averages of all the analyses of each kind (Tab. XXX). It is quite probable also that some of the coarse grains were shaken off from the adhesive surfaces. An average of these two averages may be taken as representing the nearest approximation to the composition of dust carried in the atmosphere at the

Table XXIX. **Mechanical Composition of Dust collected directly from the Atmosphere by Means of Slack Wind in a hollow Cylinder, Feb. 19, 1896.**

Length of diameter in mm.	126 Maximum hourly velocity of wind, 29 miles.
16—8	....
8—4	....
4—2	....
2—1	....
$1-\frac{1}{2}$	....
$\frac{1}{2}-\frac{1}{4}$	....
$\frac{1}{4}-\frac{1}{8}$	tr.
$\frac{1}{8}-\frac{1}{16}$	2.8
$\frac{1}{16}-\frac{1}{32}$	26.5
$\frac{1}{32}-\frac{1}{64}$	55.2
$\frac{1}{64}-\frac{1}{128}$	13.2
$\frac{1}{128}-\frac{1}{256}$	1.2

place where these observations were made. It may be collected in low winds as well as high, and though it appears to be slowly settling, its general presence indicates that it is easily held in suspension.

Table XXX. **Average Mechanical Composition of Dust caught on Adhesive Surfaces and in Slack Wind.**

Length of diameter in mm.	Average dust caught on adhesive surfaces.	Average dust caught in slack wind.	General Average.
16—8	....	....	....
8—4	....	....	....
4—2	....	....	....
2—1	....	....	....
$1-\frac{1}{2}$	....	....	....
$\frac{1}{2}-\frac{1}{4}$	tr.	....	tr.
$\frac{1}{4}-\frac{1}{8}$	tr.	.9	4.
$\frac{1}{8}-\frac{1}{16}$	6.4	14.2	10.3
$\frac{1}{16}-\frac{1}{32}$	27.0	42.8	34.9
$\frac{1}{32}-\frac{1}{64}$	44.5	30.1	37.3
$\frac{1}{64}-\frac{1}{128}$	19.6	10.4	15.0
$\frac{1}{128}-\frac{1}{256}$	1.6	.9	1.2

DUST TAKEN ON NATURAL SURFACES ABOVE THE GROUND.

Several analyses have been made of dust found adhering to surfaces of objects more or less elevated above the ground (Tab. XXXI). Eight such samples were washed from the foliage of trees, on which appreciable deposits of dust may always be observed. The maximum grade in this material is medium dust, but the lesser weight and the smaller size of the particles smaller than this renders them less subject to dislodgement by the wind and by occasional shaking and rubbing of the

Table XXXI. **Mechanical Composition of Dust Collected from Surfaces elevated some Distance above the Ground. (Unless otherwise stated the collecting was done at Rock Island, Ill.)**

Length of diameter in mm.	127 Shaken from the bark of an oak tree.	128 Taken in rain water fr. the roof of a house.	129 From rain water from the bark of an oak tree.	130 From the trunk of an oak tree.	131 Taken in rain water fr. the roof of a house.
16—8	....	....	....	....	....
8—4	....	....	....	....	....
4—2	....	....	....	....	....
2—1	....	....	....	....	....
$1-\frac{1}{2}$	tr.	2.0	....	tr.	4.0
$\frac{1}{2}-\frac{1}{4}$	tr.	1.8	....	tr.	3.0
$\frac{1}{4}-\frac{1}{8}$	.3	2.2	tr.	tr.	5.0
$\frac{1}{8}-\frac{1}{16}$	6.0	7.7	4.0	2.9	7.5
$\frac{1}{16}-\frac{1}{32}$	42.8	36.0	42.0	38.5	25.6
$\frac{1}{32}-\frac{1}{64}$	46.0	36.0	43.0	41.3	47.9
$\frac{1}{64}-\frac{1}{128}$	3.7	14.1	9.7	19.2	6.0
$\frac{1}{128}-\frac{1}{256}$	.5	.2	1.1	....	.7

leaves against each other. When collected in the early part of the summer this dust is therefore found to be coarser than it is later on, owing to the more frequent removal of the coarser particles and the more persistent adhering of the finer. In some dust which was washed from the leaves of some oak trees in the months of May and June in 1895, there was about twenty per cent of fine dust (Nos. 136, 137), while in two samples taken in August and September, there was a little over thirty per cent of the same ingredient (Nos. 138, 139), and in another sample, which was washed from leaves remaining on some trees in February, the fine dust was the maximum ingredient making nearly forty per cent of the whole sample. Four of these analyses are of dust taken on the bark of some trees, and two are of dust coming with rain

Table XXXI. **(Continued).**

132	133	134	135	136
Washed from the trunk of an oak tree.	Washed from poplar leaves.	Washed from the leaves of a hickory tree.	Washed from the leaves of a linden tree.	Washed from the leaves of an oak tree, June '95.
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....
.4	....	....	....	....
1.0	....	....	....	tr.
6.2	tr.	tr.	tr.	tr.
13.0	11.0	2.0	.8	2.0
20.1	17.0	23.0	17.8	13.0
30.1	34.0	42.0	58.7	60.0
26.0	33.0	30.0	21.9	17.0
2.5	3.0	2.0	1.3	8.0

Table XXXI. **(Continued).**

137	138	139	140	
Washed from the leaves of an oak tree, May '95.	Washed from the foliage of trees at La Salle, Ill.	Washed from the leaves of trees at New Bedford, Ill.	From dry leaves of oak trees, Feb. 1895.	Average.
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....
....	....	tr.	....	.4
....	tr.	.1	.5	.4
.2	.1	.5	1.7	1.1
2.5	1.0	1.0	3.0	4.6
16.8	17.1	17.0	20.0	24.7
57.2	40.8	44.0	27.0	43.4
22.0	31.7	32.0	38.5	21.7
3.0	8.8	7.3	9.1	3.4

water from a house-roof. Such rough surfaces as these give a secure lodgement to grains of sand as well as dust. From the analyses it is quite evident that some coarse material is moved even by the gentle winds of the Mississippi valley. It may be that many of these grains are raised by the aid of lighter objects to which they adhere, such as bits of straw and leaves. But their abundance in these last samples is best accounted for by the action of occasional strong convection currents and by the increased chances for larger grains to find lodgement on rough surfaces. This may be inferred from two analyses, one of which gives the composition of some dust collected from the trunk of a small tree by striking it repeatedly with a hammer (No. 127), while the other shows the ingredients in the material which remained on the bark after this procedure and which was secured afterward by washing (No. 132). The former has a small and the latter a large proportion of the admixtures on either side of the maximum ingredient. Aside from the greater proportions of the extreme grades, which may be accounted for by the diminished proportionate chances of the grains of the maximum ingredient to find and maintain a secure lodgement, all of these samples resemble those collected on surfaces rendered adhesive by the application of glycerine. The averages of these two series of samples correspond closely for each grade. Both are perhaps, on the whole, slightly finer than the dust which is constantly floating in the air over the central part of the upper valley of the Mississippi.

SHOWER DUST.

Deposits of an impalpable dust are sometimes observed over this region, especially during winter, when it is apt to fall on the snow and discolor its surface. It generally appears after strong westerly winds, which have been called dust storms. Eighteen samples of such dust have

Table XXXII. **Mechanical Composition of Shower Dust fallen west of the Mississippi River.**

Length of diameter in mm.	141 Dust from Kansas City, Mo.	142 Dust from Alta, Iowa, June 7, 1895.	143 Dust from Alta, Iowa, June 8, 1895.
16—8	....	....	....
8—4	....	....	....
4—2	....	....	....
2—1	....	....	....
$1-\frac{1}{2}$	....	....	......
$\frac{1}{2}-\frac{1}{4}$	....	....	....
$\frac{1}{4}-\frac{1}{8}$	2.	1.6	1.7
$\frac{1}{8}-\frac{1}{16}$	6.6	8.3	4.0
$\frac{1}{16}-\frac{1}{32}$	59.5	58.2	46.0
$\frac{1}{32}-\frac{1}{64}$	27.7	28.0	42.0
$\frac{1}{64}-\frac{1}{128}$	4.3	2.7	7.6
$\frac{1}{128}-\frac{1}{256}$	.5	.3	.7

been examined, and these represent six different storms. The coarsest fell in Kansas City in the summer of 1890. Nearly sixty per cent of its weight consists of coarse dust, and less than thirty per cent is medium dust (Tab. XXXII). Two samples taken near Alta in Iowa come next to this in coarseness. An average of the two analyses has fifty-two per cent of coarse dust and thirty-five

of the medium. This was collected during and after a heavy wind in the early part of June in 1895.

Thirteen samples were gathered from the surface of ice and from snow at Rock Island in Illinois and these represent three different showers. One such shower occured in the latter part of November in 1894 (Tab. XXXIII), one in the latter part of January in 1895 (Tab. XXXIV),

Table XXXIII. **Mechanical Composition of Shower Dust fallen at Rock Island, Ills., November, 1894.**

Length of diameter in mm.	144 Taken on the ice of a small pond.	145 From the ice of the Mississippi near the bank.	146 From the ice of the Mississippi, centre of channel	Average.
16—8	....	....	....	....
8—4	....	....	....	....
4—2	....	....	....	....
2—1	....	....	....	....
$1-\frac{1}{2}$	.2	tr.	....	.1
$\frac{1}{2}-\frac{1}{4}$	2.5	.5	....	1.0
$\frac{1}{4}-\frac{1}{8}$	6.4	3.4	1.0	3.6
$\frac{1}{8}-\frac{1}{16}$	13.5	15.0	8.9	12.5
$\frac{1}{16}-\frac{1}{32}$	50.0	33.0	33.4	38.8
$\frac{1}{32}-\frac{1}{64}$	25.6	43.0	46.8	38.5
$\frac{1}{64}-\frac{1}{128}$	.9	4.3	8.9	4.7
$\frac{1}{128}-\frac{1}{256}$	....	.7	5.	.4

and one in February in 1896 (Tab. XXXV). The selection of these samples was made with a view to find out not only the average composition of the sediment from each shower but also the range of variation in composition which might be due to changes in convection currents in the atmosphere and to the admixture of local material. Dust gathered on the ice close to land contains compar-

Table XXXIV. **Mechanical Composition of Shower Dust fallen at Rock Island, Ill., January, 1895.**

Length of diameter in mm.	147	148	149	150	151	Average.
	From the ice of the Mississippi, near bank.	From the ice of the Mississippi, near bank.	From a crack in ice of the Mississippi, in channel.	From the ice of the Mississippi, centre of the channel.	From the ice of the Mississippi, near the bank.	
16—8	....	....	....	....	....	....
8—4	....	....	....	....	....	....
4—2	....	....	....	....	....	....
2—1	....	....	....	....	....	....
$1—\frac{1}{2}$	....	....	....	....	....	....
$\frac{1}{2}—\frac{1}{4}$	tr.	1.2	.5	....	tr.	.3
$\frac{1}{4}—\frac{1}{8}$	2.0	10.9	1.4	.7	.2	3.1
$\frac{1}{8}—\frac{1}{16}$	18.0	13.8	15.2	9.0	11.2	13.0
$\frac{1}{16}—\frac{1}{32}$	32.0	41.5	44.6	36.3	30.0	36.9
$\frac{1}{32}—\frac{1}{64}$	37.0	29.8	34.0	36.3	49.0	37.2
$\frac{1}{64}—\frac{1}{128}$	9.0	3.9	4.7	15.1	7.0	7.9
$\frac{1}{128}—\frac{1}{256}$	7.0	....	.3	1.8	1.1	.8

Table XXXIV. (**Continued**).

atively large quantities of coarse admixtures, evidently derived from the ground close by (Nos. 144, 145, 147, 148, 151), and the same is the case with some material which had accumulated in a long crevice in the ice, across which the wind had been drifting after the deposit had settled (No. 149). The dust taken near the center of the channel of the Mississippi river has less of the coarse admixtures, as does also that taken on snow (Nos. 146, 150, 152, 153, 154, 155, 156).

Table XXXV. **Mechanical Composition of Shower Dust fallen at Rock Island, Ill., February, 1896.**

Length of diameter in mm.	152	153	154	155	156	Average.
	From snow in timber.	From snow just above the river bluffs.	From snow near a ravine.	From snow close to a tree.	From snow on an open field.	
16—8	....	....	....	....	....	....
8—4	....	....	....	....	....	....
4—2	....	....	....	....	....	....
2—1	....	....	....	....	....	....
$1—\frac{1}{2}$	....	....	....	....	....	....
$\frac{1}{2}—\frac{1}{4}$	....	....	....	....	....	....
$\frac{1}{4}—\frac{1}{8}$	.3	.3	1.2	tr.	tr.	.4
$\frac{1}{8}—\frac{1}{16}$	5.7	7.3	4.4	3.2	1.6	4.4
$\frac{1}{16}—\frac{1}{32}$	49.9	47.9	40.7	43.9	30 9	42.6
$\frac{1}{32}—\frac{1}{64}$	39.2	38.2	44.0	46.5	54.3	44.4
$\frac{1}{64}—\frac{1}{128}$	4.7	6.3	7.9	5.6	11.4	7.2
$\frac{1}{128}—\frac{1}{256}$	.3	.2	.4	.3	.4	.3

Table XXXV. **(Continued).**

Over level areas, as out on the ice of the river away from the banks, and on an open field, a greater proportion of fine dust is noticeable (Nos. 146, 150 156), due most likely to a more even progression of the atmosphere permitting more of its load to settle, while near places where timber or topographic contours had set up convection currents, less of the finer dust seems to have been able to come down (Nos. 144, 152, 153). In the averages from each of these three showers the me-

dium and the fine dust are present in nearly equal proportions and constitute from seventy-four to eighty-seven per cent of the whole. In the samples collected on the ice, there is nearly three times as much of the two grades of sand as in those taken on snow, owing, it seems, to the greater quantity of local drift raised by the wind from bare ground along the banks of the river.

Table XXXVI. **Mechanical Composition of Shower Dust, Averaged for five Localities.**

Length of diameter in mm.	Kansas City, Mo.	Alta, Iowa. (Average).	Rock Island, Ill. (Average).	157 Chicago, Ill.	158 Maysville, N. Y.
16—8	....	....	....	....	....
8—4	....	....	....	....	....
4—2	....	....	....	....	....
2—1	....	....	....	....	....
1—$\frac{1}{2}$	....	....	tr.	.2	....
$\frac{1}{2}$—$\frac{1}{4}$	....	....	.4	3.0	.9
$\frac{1}{4}$—$\frac{1}{8}$	.2	1.6	2.1	5.5	.9
$\frac{1}{8}$—$\frac{1}{16}$	6.6	6.1	9.6	7.8	4.1
$\frac{1}{16}$—$\frac{1}{32}$	59.5	52.1	39.5	31.5	16.0
$\frac{1}{32}$—$\frac{1}{64}$	27.7	35.0	40.3	36.2	53.6
$\frac{1}{64}$—$\frac{1}{128}$	4.3	5.1	6.9	14.1	22.0
$\frac{1}{128}$—$\frac{1}{256}$	.5	.5	.5	1.5	2.0

A sample of dust was taken just west of Chicago, soon after the shower which occurred in the latter part of February in 1896 (Tab. XXXVI). It contains a considerable admixture of local coarse fragments, but aside from this it is slightly finer than the average deposit from the same storm at Rock Island. Still another sample was collected at Maysville in New York, after this storm. This also contains a small quantity of sand, but it is otherwise the

finest of all the samples of the shower dust examined, having a larger percentage than the rest of all the grades containing particles less than one thirty-second of a millimeter in diameter.

The common belief that this shower dust is brought from distant places receives some support from the wide

Table XXXVII. **Mechanical Composition of Storm Dust; (an average for eighteen samples).**

Length of diameter in mm.	Average.
16—8	....
8—4	....
4—2	....
2—1	....
1—$\frac{1}{2}$	tr.
$\frac{1}{2}$—$\frac{1}{4}$	.5
$\frac{1}{4}$—$\frac{1}{8}$	2.1
$\frac{1}{8}$—$\frac{1}{16}$	8.6
$\frac{1}{16}$—$\frac{1}{32}$	40.3
$\frac{1}{32}$—$\frac{1}{64}$	39.5
$\frac{1}{64}$—$\frac{1}{128}$	7.8
$\frac{1}{128}$—$\frac{1}{256}$	.6

Table XXXVIII. **Average Mechanical Composition of 57 samples of Atmospheric Dust.**

Length of diameter in mm.	Average.
16—8	....
8—4	....
4—2	....
2—1	....
1—$\frac{1}{2}$	.1
$\frac{1}{2}$—$\frac{1}{4}$	.2
$\frac{1}{4}$—$\frac{1}{8}$	1.1
$\frac{1}{8}$—$\frac{1}{16}$	7.9
$\frac{1}{16}$—$\frac{1}{32}$	33.1
$\frac{1}{32}$—$\frac{1}{64}$	40.4
$\frac{1}{64}$—$\frac{1}{128}$	14.9
$\frac{1}{128}$—$\frac{1}{256}$	1.6

areal extent of the storms which bring it. The prevailing westerly direction of the winds in these latitudes, taken in connection with the gradual change exhibited by these samples (see Tab. XXXVI) from coarse in Missouri to fine in New York, may be looked upon as supporting the same view. This change in the deposits may be the result of a slow sifting out of the coarser particles during transit

from west to east. But with only a single sample from three of these places and only two from another, this evidence is of little weight. Again, it seems quite certain that part of the shower dust is local material. This is indicated not only by the sand it contains, but also by the color of the deposit. When collected from regions where there is a rich black soil, it is apt to be dark, and when observed in the lee of sandy and less fertile lands, it is brownish or reddish. It appears most probable, that part of the shower dust comes directly from distant places, while a part is picked up from the ground nearer to the place where it falls, or from the surface of plants, on which it has previously lodged. Som other observations indicate that there is a constant migration of dust particles in the lower part of the atmosphere. These are apparently picked up and let down unceasingly by the wind. Just what proportion of the deposits which settle from this migrating dust at any particular place or time, is local, and just how much of it comes directly from distant places, is difficult to say. That coarse dust is capable of being transported long distances in the atmosphere can, however, under no circumstances be doubted. It floats along in considerable quantities even on the calmest days when the maximum hourly velocity of the wind does not exceed ten or fifteen miles. It constitutes from twenty-two to forty-four per cent of the totals of the dust caught on such days (Nos. 102, 107, 108, 109, 110, 118), and the smallest proportion which it forms in any of the fifty-seven samples of fine atmospheric sediments I have examined, is thirteen per cent (No. 136). It seems safe to conclude that dust, which is present in such

quantity in the atmosphere, even in calms, cannot escape being carried a hundred miles or more in a strong wind. Medium dust must be capable of being transported still farther and fine, and very fine dust evidently settle with great slowness even in perfect calm, unless present in such quantity that flocculation will take place. This probably seldom occurs except near places of active wind erosion.

If we now take a review of all the analyses of atmospheric dust here presented, that artificially collected as well as the storm dust, we notice that the maxima are scattered over three grades. In sixteen samples the maximum occurs in the coarse dust, in two it is right between this and the medium dust, in thirty-eight of the samples it occurs in the medium dust, and in one it is in the fine dust. This one sample was collected from dried foliage exposed to the winds for several months, during which time a large proportion of the coarser particles had, no doubt, been dislodged. In all the cases where the maxima consist of coarse dust (except perhaps nos. 152, 153), special conditions of collecting account for the greater quantity of coarse materials. The diversity in composition of the atmospheric dust is hence more apparent than real. In two of the samples ninety per cent is distributed among five different grades; in seventeen samples, among four; in thirty-six, among three grades, and in one sample it is divided between two. The average position of the precise maximum (as we may designate that length of diameter, which, if taken as a limit for separation, would divide the bulk of the dust into two equal parts) appears to be a little below but not far removed from the limit between the coarse and

the medium dust. This in part accounts for the low percentages of the maxima, which never exceed sixty per cent of the entire weight of each sample and which range down to thirty. The decrease from the maximum to either extreme ingredient is uninterrupted, except in two samples collected from rain-water, which came from the roof of a house. In these the coarse sand is present in greater quantity than the medium sand. The slope from the maximum toward the coarse admixtures is more gradual than that toward the fine admixtures in nineteen of the samples. Most of these were taken near the surface of the ground in places favorably situated for the admixture of local material, as from the trunks of trees, from house-roofs, from ice near river banks, and from snow near bare patches of ground. In thirteen samples the decrease is, on the other hand, rather more gradual toward the fine admixtures. Such is nearly always the case when the dust has settled in slack wind, as in the hollow cylinder, among the trees, or under shelter. In twenty-five samples the two slopes are about equally steep. These include most of the dust caught on surfaces smeared with glycerine and some of the shower dust. In an average of all the samples, owing to the large admixture of local coarse materials in a few instances, the slope is more gradual in the direction of these admixtures. But the difference is slight (Tab. XXXVIII).

The significance of this last feature is quite evident. The elimination of the sand from the settling dust follows the same law as the separation of material which is still finer, from this dust. The greater vertical components in the wind near the surface of the ground are able to keep

the dust in suspension, while sand is dropped, and in the same way lesser vertical components higher up in the air mostly retain particles less than one sixty-fourth of a millimeter in diameter, while particles larger than this are slowly settling. Where no exceptional conditions prevail, the two slopes should therefore be symmetrical, since both are determined by the velocity of the atmospheric currents.

GENERAL CONCLUSIONS.

While the wind-borne materials which were collected for these analyses may not represent the greatest extremes of wind work, such extremes were sought in their selection. Even if more extended observation should show, as it hardly can fail to do, that pebbles considerably larger than any seen in these samples, may be moved by the wind, it is evident that atmospheric transportation is confined to rock fragments of comparatively limited range of sizes. The largest pebble found in any of these analyses, measured less than eight millimeters in diameter. In the opposite direction infinity is of course the extreme limit, but in the dust collected for this study the quantity of particles measuring less than one two hundred and fifty-sixth of a millimeter in diameter probably in no case amounted to as much as one per cent of the whole, and generally it constituted merely a trace, when at all present. It was therefore neglected in the analyses.

The limited range of coarseness of wind-borne materials is, of course, due to the lightness of the air. Within

the same limits of velocity a lighter medium will not move such large fragments as a heavier. Water currents dislodge masses immensely greater than the largest pebble in these samples. As a result of this restriction on the work of the atmosphere, its deposits are necessarily less diverse in their mechanical composition than those of water.

Another circumstance, which increases the uniformity of atmospheric sediments, is the great effectiveness of the atmosphere as a sorting agent. In different media the sorting power increases with the decrease of the carrying power. It is a familiar fact, that moving glacier ice can effect no sorting. In the same way a highly viscous liquid is a bad sorter, for its motion is slow, and the small particles it carries are not brought sufficiently far ahead of the larger ones.

In a current of water the velocity is greater and the different grades of fragments are farther removed from each other in a horizontal direction, before all have time to sink. In the much lighter air this separation is still wider, owing to the higher velocities which obtain, and still more perfect sorting is the result. Whatever the air lacks in viscosity and weight must be made up by velocity of its currents, if any material at all shall be transported.

It might be inferred that this great sorting power of the atmosphere should produce diversity rather than uniformity in the deposits.*) Such is indeed the case whenever the load, dropped during each transient period of somewhat uniform velocity, is sufficient in amount to

*) See letter from Prof. Dana, Journal of Geology, Vol. III, p. 342.

appear as a distinct layer in the deposit. But this probably never occurs except in the drifting dunes, and near them. In dune sand the most perfect lamination is often to be seen, even when the actual difference in the coarseness of the separate seams is very small (Nos. 47, 48). The deposits which accumulate nearest in the lee of drifting tracts may also sometimes become more or less stratified, when coarse layers from exceptionally heavy storms are thick enough to remain separate. This does not always happen, for rains and growing plants are effective agents in mingling successive laminae, when not too thick, into a homogeneous unstratified mass.

But the lulls which occur even in the strongest winds soon cause the coarser particles of their load to fall out, and after a while only the finer ones remain suspended. This is plainly indicated by the composition of the samples of sand, which were collected in front of dunes (Nos. 64, 75). As the wind travels away from the place of loading, its many convection currents, turns, and windings cause it to disperse vertically and horizontally, and the load is *pari passu* dispersed and thinned. From such an atmosphere sedimentation is very slow. From each transient current, marked off by cyclonic, diurnal, or shorter irregular periods, deposits are laid down, which no doubt are different from each other in mechanical composition, but the quantity from each is never sufficiently great to form a separate lamina. Each deposit is thoroughly mingled with that which has settled before, either by the settling of the particles of the latest deposit in the interstices of that laid down before, as this is not thick enough to completely cover the ground surface, or

else by the subsequent superficial mixing effected by various forces. Such mixing results from the direct action of the winds; indirectly, from the action of the wind on various objects which are caused to move on the surface of the ground; from rain; from frost; from the works of insects and other small animals; and from growing plants. All these agencies acting together can hardly fail to prevent any sub-aerial deposit of dust from acquiring such a fine lamination as is often seen in silts and clays, which are deposited under water and which have accumulated much more rapidly. Eolian loess is never markedly laminated, and the primary cause of the absence of this structure is the great velocity of the atmospheric currents, which scatter the materials in suspension over so wide areas that the deposit from each passing current becomes too small to remain as a distinct layer.

These analyses plainly indicate that atmospheric sediments are rendered uniform also by the elimination of the finest particles, such as measure less than one one-hundred-and-twenty-eigth of a millimeter in diameter, and even to some extent the particles of the next coarser grade. It will be noticed that the very fine dust in but a few cases exceeds three per cent of the total weight of each sample examined. The fact that this fine material is not specially abundant in the dust caught on the calmest days indicates that it is easily held in suspension. This is no doubt the kind of dust which follows the wind around the globe. It is carried everywhere and must be settling everywhere in exceedingly small quantities, inversely proportionate to the greater area over which it is being

spread. Falling on the land it will be washed away by erosion or enter as an inconspicuous component in the coarser atmospheric dust, and falling in the sea it will be lost among the more copious aqueous sediments there, unless places exist where these are absent. On account of this slow settling of the finest dust we cannot expect to find it forming separate laminae in eolian deposits, for over regions where these are built up, the wind will never remain quiet long enough to permit a sufficient quantity of only fine material to settle and form such layers.*) It appears therefore that the finest wind sediments, which may be laid down in such quantity as to form appreciable deposits, consist in the main of particles ranging from coarse to fine dust, and do not have any markedly laminated structure.

SUMMARY.

The work of the atmosphere begins with erosion. This erosion is confined to much smaller areas than atmospheric sedimentation. One such area of erosion may be regarded as one of the corners of an isosceles triangle, pointing against the wind. Between the two equal sides of this triangle transportation and sedimentation is taking place. The quantity of work performed is greatest near the area of erosion. In this area materials of varied coarseness are moved, up to pebbles which measure at least eight millimeters in diameter. Deposition of the coarsest material, such as gravels, takes place immediately. They are left as a thin veneer on the surface,

*) It is interesting to notice that separate layers of such fine material are seldom absent from the silts and clays deposited in water.

and this tends to prevent further erosion. The coarser grades of sand, those containing grains from one to one fourth of a millimeter in diameter, are dragged along a greater distance, but they are unable to keep pace with dune sand, which is mostly finer. When present in sufficient quantity in the eroded terrane, the medium and the fine sand, and especially the latter, are heaped up into the dune drifts. These may creep over considerable distances in course of time. The sand grains which measure from one half to one eight of a millimeter in diameter, do not seem to be lifted very far in a single leap by the strongest wind, probably seldom as far as a few hundred yards, and much more often only a few feet. The very fine sand, which is next in texture, appears to be mostly dropped before it is carried many miles. Course dust remains much longer in suspension. Most of it probably settles before it is carried two or three hundred miles. The general presence in all kinds of winds of medium dust renders it likely that much of this may be carried as far as five hundred or a thousand miles before having time to settle. Dust finer than this is no doubt carried still farther. It must be largely scattered around the globe and is perhaps often kept floating, until it is brought down by rain. It should be understood that these estimates are for such winds as prevail over the continents. In a tabular form they may be stated thus:

Table of Approximate Maximum Distances over which Quartz Fragments of Different Dimensions may be lifted by Moderately Strong Winds in Single Leaps.

Gravel (diameter from 8—1 mm.)	A few feet.
Coarse and medium sand (diam. 1—$\frac{1}{4}$ mm.)	Several rods.
Fine sand (diam. $\frac{1}{4}$—$\frac{1}{8}$ mm.)	Less than a mile.

Very fine sand (diam. $\frac{1}{8}$—$\frac{1}{16}$ mm.)..................A few miles.
Coarse dust ($\frac{1}{16}$—$\frac{1}{32}$ mm.)................................200 miles.
Medium dust ($\frac{1}{32}$—$\frac{1}{64}$ mm.)...............................1,000 miles.
Fine dust ($\frac{1}{64}$ mm. and less)...........................Around the globe.

It is evident that the place of greatest deposition is never far from the place of greatest erosion, when the eroded terrane consists of coarse as well as fine materials. It is generally marked by the accumulation of dune sand. From this point deposition decreases, owing to the transversely horizontal and the vertical dispersion of the load by spreading winds and owing to the previous settling of the coarser particles. A limit is sooner or later reached, where aqueous erosion is more rapid than the accumulation of atmospheric sediments. Beyond this limit the latter will of course not appear.

It is also evident that *the different grades of materials are so far separated from each other in the direction of the wind movement, that even with considerable changes in velocity, the principal area of the deposition of sediments of one grade will not far encroach upon that of the deposition of materials much coarser or much finer.* Gravel or coarse sand, for instance, will never be carried to the region of the main dust deposit, nor will the fine sand. For any particular locality a wind sediment will hence be quite uniform in composition in a single triangle.

In nature we must, however, expect to find a multiplicity of these triangular areas of wind action, wherever the conditions are such that erosion by the atmosphere may take place. They must be found overlapping and inclosing each other. The sediment in any particular place may hence be found to contain grains of varied

coarseness, within the limits of the transporting power of the air, and the proportion of the different ingredients will be determined by the position of the place of its accumulation with regard to different areas of erosion. Small areas of erosion are found almost everywhere, and local material will therefore seldom be absent from any wind deposit. Should places of erosion be numerous in any particular region this may itself be regarded as the windward angle in a great triangle with a great area of deposition to the leeward.

THE PROBLEM OF THE LOESS.

It seems probable that the Western plains and the Mississippi valley maintain the windward-leeward relation to each other. Dust which is stirred up over the plains must be carried east by the prevailing winds, and a part of it no doubt settles over the great central valley. The loess and surface silts, which are spread over most of the territory in this valley, resemble atmospheric sediments considerably in their mechanical composition.*)

It is generally finer in the east and coarser in the west, and it decreases in thickness from west to east. The question whether it is, in the main, aqueous or eolian, cannot be considered as yet settled. It seems doubtful if the deposition at present exceeds erosion over all of this area, but a very slight change in elevation or in climate may lately have reversed the condition in this respect. The question of changed conditions is a very complex one.

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*) See *Report on the Examination of Some Soils from Illinois*, by Milton Whitney in the *Report of the Illinois Board of World's Fair Commissioners;* also *Preliminary Report of the Driftless Area of the Upper Mississippi Valley*, by Chamberlin and Salisbury.

The following statements, which were made in a letter written by Professor Dana just before his death, set forth certain objections to the eolian hypothesis. "With regard to the eolian work along valley plains, I think great caution is necessary because eolian work is of a fitful kind. The more powerful winds blow in gusts or rather a succession of them, and each of the gusts is of a rather narrow limit; and in each gust great velocity is succeeded by a decline in which the depositions vary accordingly as to fine and coarse and limit. Making loess — unstratified — by the winds would require a steady breeze sufficient to move the light earth or sand long in a common direction, but too near unvarying in force or velocity to produce alternations from coarse to fine. It is an even kind of work that winds are not often fit for."*) In the last edition of Dana's classic Manual the correctness of Richthofen's theory of the Chinese loess is regarded as improbable owing to the absence of winddrift structure (lamination)**). Possibly the absence of such structure was Dana's chief objection to an eolian hypothesis of the origin of the American loess. His argument that the deposit from every changing gust of wind must vary in coarseness according to the velocity, expresses a general law which certainly is true, but it seems that there are some special conditions which supervene, as explained above, and that these will necessarily modify the results of the operation of this law and limit its application to such deposits as are accumulating rapidly near places of atmospheric erosion.

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*) See Journal of Geology, Vol. 3, p. 342.

**) Manual of Geology, p. 195.

Other objections to an eolian origin of the American loess have been made. These refer especially to some geographical features, which cannot be considered here, but which will nevertheless have to be taken into account in a full discussion of the subject. Some distinguished American students of this puzzling formation appear inclined to suspend judgment or to ascribe its genesis to several distinct processes. Though the eolian hypothesis has been more or less considered by all geologist who have had occasion to study the loess, it seems that the nature of the work really performed by the atmosphere is too imperfectly known to admit, as yet, of any thorough discussion of the efficiency or inefficiency of the wind as a loess-maker in America. A study of this work should precede a final verdict on the origin of this formation, and this thought has been a stimulus while pursuing the studies whose results are here recorded. Further studies of this kind coupled with a careful examination of the loess and associated silts in all their varied phases promise to aid in the eventual solution of the "problem of the loess".